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Proposed Metrics For IAQ in Low-Energy Residential Buildings

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The overall objective of the International Energy Agency project, Energy in Buildings and Communities *Annex 68 "Indoor Air Quality Design and Control in Low-energy Residential Buildings,"*[1] is to provide a scientific basis for optimal and practically applicable design and control strategies for high IAQ in residential buildings. An obstacle for close integration of energy and IAQ strategies in building design and optimization is the lack of an index that can quantitatively describe indoor air quality (IAQ) and be compared with indices that describe energy performance. The first phase of the Annex 68 project was to develop such an IAQ index for low-energy residential buildings. The purpose of the metric was to define the pollutants that should be modeled when hygrothermal processes are simulated and to assess the performance of the solutions and their effectiveness.

In September 2017, the Air Infiltration and Ventilation Center (AIVC) published a report describing the employed methodology and results.[2] The approach can be summarized as follows. In a first phase, we selected target indoor air pollutants, i.e., pollutants listed by cognizant authorities as being harmful for humans during short-term (<24 hours) or long-term (>week) exposures. Then, we checked whether these compounds were measured by published studies in residential environments and at concentrations that exceed the levels identified in the first phase. In a second phase, we reviewed previously proposed IAQ metrics to identify the different approaches used in the past and to judge whether any of them would be useful to define the best science-based indices for evaluation of IAQ. We proposed IAQ sub-indices based on acute and chronic effects as the ratio of the concentrations to the guideline levels; for chronic effects, we also proposed the DALY approach (Disability-Adjusted Life Years) as an IAQ index. As for the multipollutant index, we proposed the maximum of the calculated indices acknowledging limitations and inaccuracies introduced by aggregation methods. Finally, the value of the index, or set of sub-indices, for IAQ ultimately needs to be weighed against the additional use of energy needed to improve IAQ in comparison with current standard practice.

Is Exposure to Pollutants Lower in Low-Energy Buildings Compared to Non-Low-Energy Buildings?

Figure 1 shows the annual average concentrations of pollutants in low-energy and non-low-energy residential buildings based on 15 different published studies from 10 countries.[2] Among the 23 pollutants, 17 have lower average concentrations in low-energy residential

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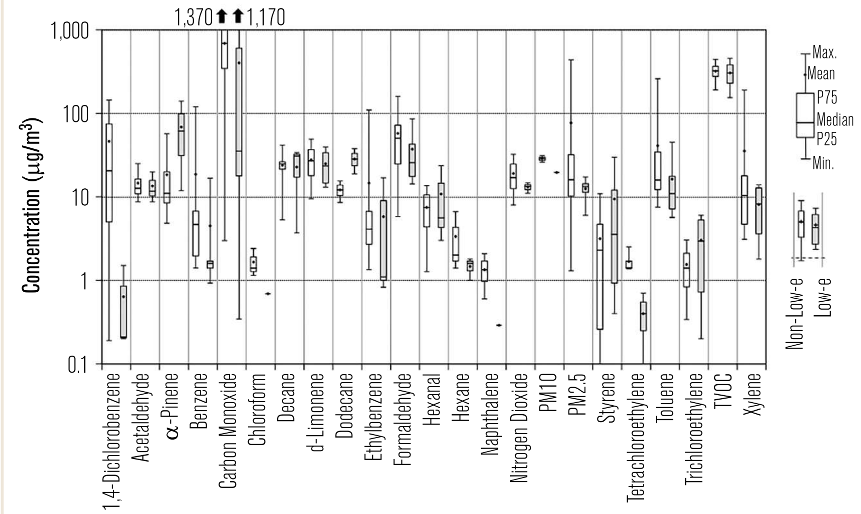
buildings. Many factors can impact the measured concentrations and cause differences between low-energy and non-low-energy buildings, including emission of pollutants, age of building, ambient air pollution and outdoor air supply rates. The concentrations were not adjusted for these factors, and, therefore, the comparisons can be considered as crude.

FIGURE 1 Average concentration of pollutants in low-energy and non-low-energy residential buildings.



What Are the Target Pollutants in Low-Energy Buildings?

Pollutant concentrations can be compared with the relevant Exposure Limit Values (ELVs) for short- and long-term exposure to judge potential health impacts. Cognizant health authorities establish ELVs nationally and internationally. The levels may be significantly different for the same pollutant and the same exposure time depending on the criteria used by the committees setting the guideline values. To come up with a unique value for each pollutant, we chose the minimal value among ELVs suggested by health agencies from around the world. This approach will ensure that minimal risk is present. By comparing ELVs and the data for concentration of pollutants (*Figure 1*), we created a shortlist of 14 pollutants (acetaldehyde, α-pinene, benzene, carbon dioxide, formaldehyde, naphthalene, nitrogen dioxide, particulate matter <10 μm PM10, PM2.5, radon, styrene, toluene, trichloroethylene and TVOC).* We acknowledge that the data can be collected with different accuracies and with different sampling methods but we were not able to make any adjustments for this because of the lack of information. Two contaminants not measured in low-energy buildings were also added: acrolein (considered as a pollutant with very high priority by References 3 and 4) and mold as an indicator for dampness that has been correlated to adverse effects on human health.[5] *Table 1* lists the pollutants selected and their ELVs, median and maximal concentrations in the low-energy and non-low-energy residential buildings studied.

TABLE 1 Pollutants relevant within the scope of IEA EBC Annex 68; concentration is given in µg/m³ except for carbon dioxide which is in ppm, radon which is in Bq/m³, and mold given in CFU/m³.

POLLUTANTS	LONG-TERM EXPOSURES		SHORT-TERM EXPOSURES		CONCENTRATION IN NON-LOW-ENERGY BUILDINGS		CONCENTRATION IN LOW-ENERGY BUILDINGS	
	ELV[a]	Averaging Period	ELV[a]	Averaging Period	Median	Maximum	Median	Maximum
Acetaldehyde	48	1 Year	–	–	12.6	25.1	11.7	20.0
Acrolein	0.35	1 Year	6.9	1 h	0.7	1.1	–	–
α-pinene	200	1 Year	–	–	11.0	57.0	61.5	140
Benzene	0.2	Whole Life	–	–	4.7	120	1.6	16.8
Carbon Dioxide	–	–	1,000	8 h	–	–	–	–
Formaldehyde	9	1 Year	123	1 h	50.5	160.0	25.9	86.0
Naphthalene	2	1 Year	–	–	1.4	2.1	0.3	0.3
Nitrogen Dioxide	20	1 Year	470	1 h	17.1	32.5	13.4	14.9
PM10	20	1 Year	50	24 h	28.7	31.3	19.7	19.7
PM2.5	10	1 Year	25	24 h	16.2	436.0	13.3	17.4
Radon	200	1 Year	400	8 h	–	–	35.5	35.5
Styrene	30	1 Year	–	–	2.3	10.9	3.6	30.0
Toluene	250	1 Year	–	–	16.0	260	11.0	45.2
Trichloroethylene	2	Whole Life	-	-	1.4	3.0	2.95	6.0
TVOC	–	–	400	8 h	322.1	443.0	304.5	455.0
Mold	200	1 Year	–	–	–	–	–	–

[a]See report for references of ELVs.[2]

* Total volatile organic compounds.

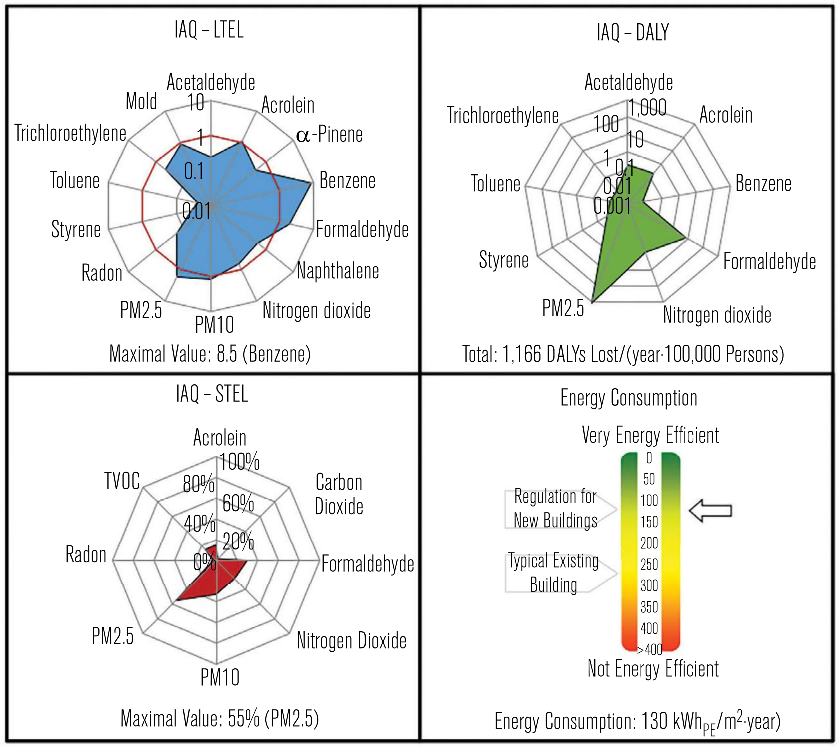
How to Quantify IAQ?

In this project, sub-indices per pollutant were calculated as the ratio of the concentration to a reference value. Following the conclusions of Reference 6, the multipollutant index was defined as the maximal value of the sub-indices. In addition, DALYs were calculated for each pollutant and added up to estimate the burden of disease caused by all exposures indoors. This approach has been used by[4] to estimate the healthy life years lost due to the exposure to indoor pollutants.

Three IAQ indices were proposed in the project. The first index is the IAQ-STEL index (Short-Term Exposure Limit) and represents the risks associated with short-term exposure to pollutants. Its calculation is based on the ELVs for short-term exposure and gives the frequency that the pollutant concentration is exceeded over a longer calculation period (days, weeks, or a year). Regarding the risks associated with long-term exposure to pollutants, two indices are considered: the IAQ-LTEL index (Long-Term Exposure Limit) is calculated as the ratio of the pollutant concentration over the ELV for long-term exposure, and the IAQ-DALY index is calculated using DALYs.

The highest values separately for IAQ-STEL and IAQ-LTEL indices are selected to form multipollutant indices. IAQ-DALY is derived by calculating DALYs for all pollutants and summing them up. The IAQ-STEL and IAQ-LTEL indices indicate whether the concentration of a pollutant is above or below its exposure limit. IAQ-DALY provides information on the burden of disease that is associated with the exposure. Thus, it provides information on the associated risks that are relevant for policy and decision makers. Thus, the two approaches and three indices are complementary.

FIGURE 2 Building IAQ and energy signature. An example of graphical presentation of IAQ indices describing air quality in a building and the status of the energy consumption. Data are for illustration only and do not represent any actual situation.



Can We Aggregate IAQ and Energy Into One Index?

Most actions to reduce the concentration of pollutants in indoor spaces require use of energy, such as increasing the rate of ventilation with outdoor air, use of air cleaners, or local exhaust hoods. It is important to have information on energy consumption related to IAQ management. Modeling tools such as those used in building energy simulation can be coupled with models for IAQ calculation to allow analyses that consider both energy consumption and IAQ. A prerequisite to aggregate energy and IAQ indices is that both are measured on the same absolute scale, which they are not. Monetizing the effects of IAQ and energy could be a way to bring both indices to the same scale. Monetizing IAQ has recently been shown by References 7 and 8, but many questions remain before it can become standard practice. Even if such an approach could be used for a limited number of pollutants, there is currently too little data to extend this approach to all the pollutants listed in this study. We have therefore decided to consider energy consumption (evaluated in primary energy consumption) separately from the IAQ indices.

The Annex 68 IAQ Dashboard

Figure 2 provides a graphical representation of the IAQ indices (IAQ-STEL, IAQ-LTEL and IAQ-DALY) along with energy consumption. Taking formaldehyde as an example, IAQ-STEL = 30% (concentration exceeds the ELV for short-term exposure 30% of the time), IAQ-LTEL = 2 (average concentration is twice the ELV for long-term exposure) and IAQ-DALY = 7.5 DALYs lost/(year·100,000 persons). From a broad point of view, efforts should be to limit the peaks of PM2.5 (IAQ-STEL = 55%) and benzene average concentration (IAQ-LTEL = 8.5). Along with this IAQ signature, the building energy consumption is provided to illustrate the energy consequences of IAQ remediation.

Summary

The IEA EBC Annex 68 project has proposed three IAQ indices, the use of which however is challenged by the number of pollutants and the need to quantify their concentrations in short and long periods to identify peaks and representative average values. However, although the proposed IAQ indices are crude, they can give a first estimate of the potential risks that are associated with exposure to pollutants and give rough estimates of the effectiveness of actions that are made to improve IAQ.

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